L3 Communications
SPD Technologies, Inc.
Power Systems Group

AEPS 2002

Performance / Application of PCM-3 & SSQS

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Presentation

- Successful completion of two separate programs that started under PEBB initiative
- Transition of the two programs into Military & Commercial arena
  - Submarine and Fuel cell Energy Storage systems
- Outline the benefits for Future Naval applications

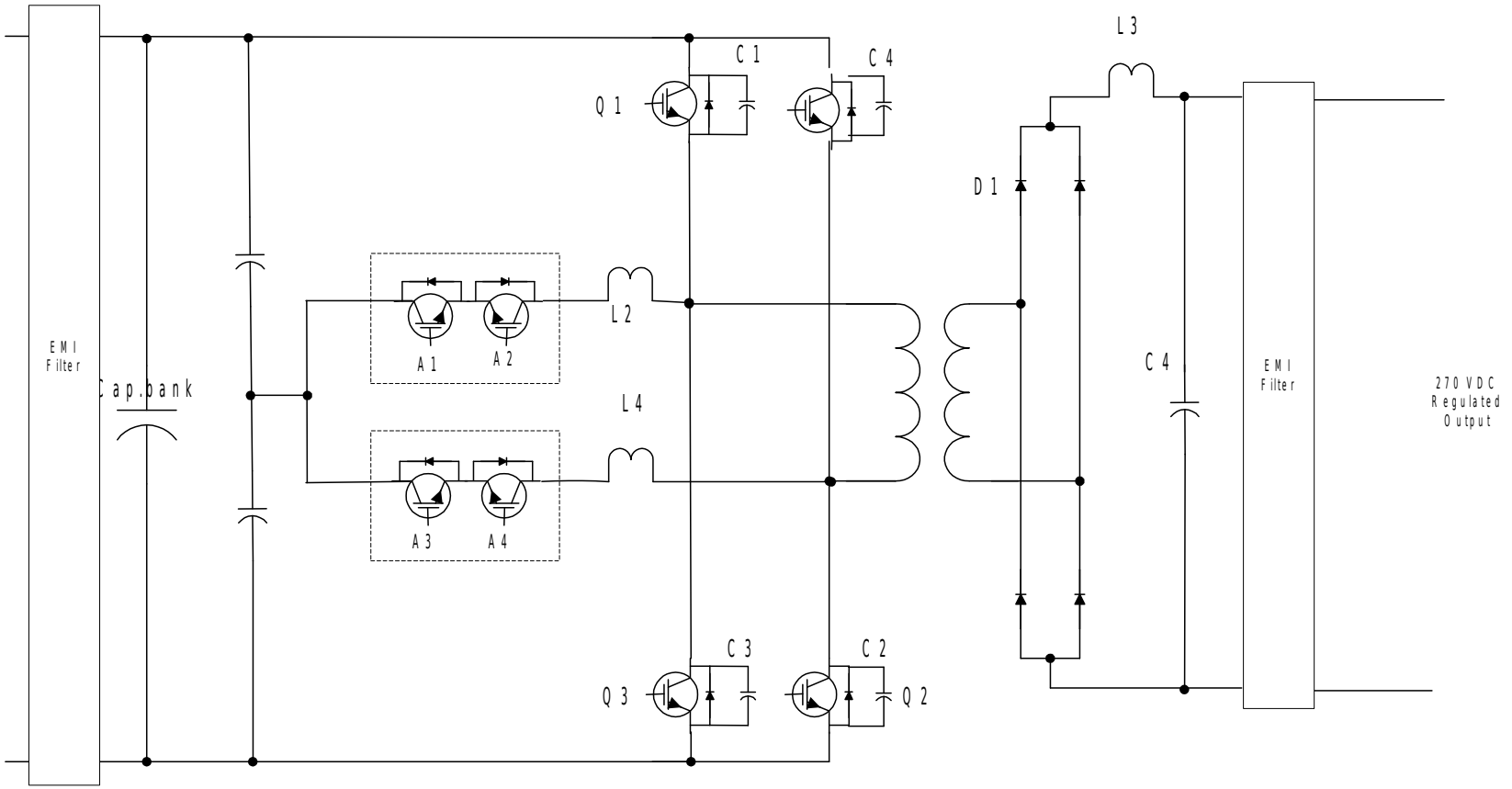
PCM-3 & SSQS

- Auxiliary Resonant Commutated pole (ARCP) high power, high frequency, isolated DC-DC converter (**PCM-3, Version 2**)
- Advanced SABT, Solid state quiet switch (**SSQS**)

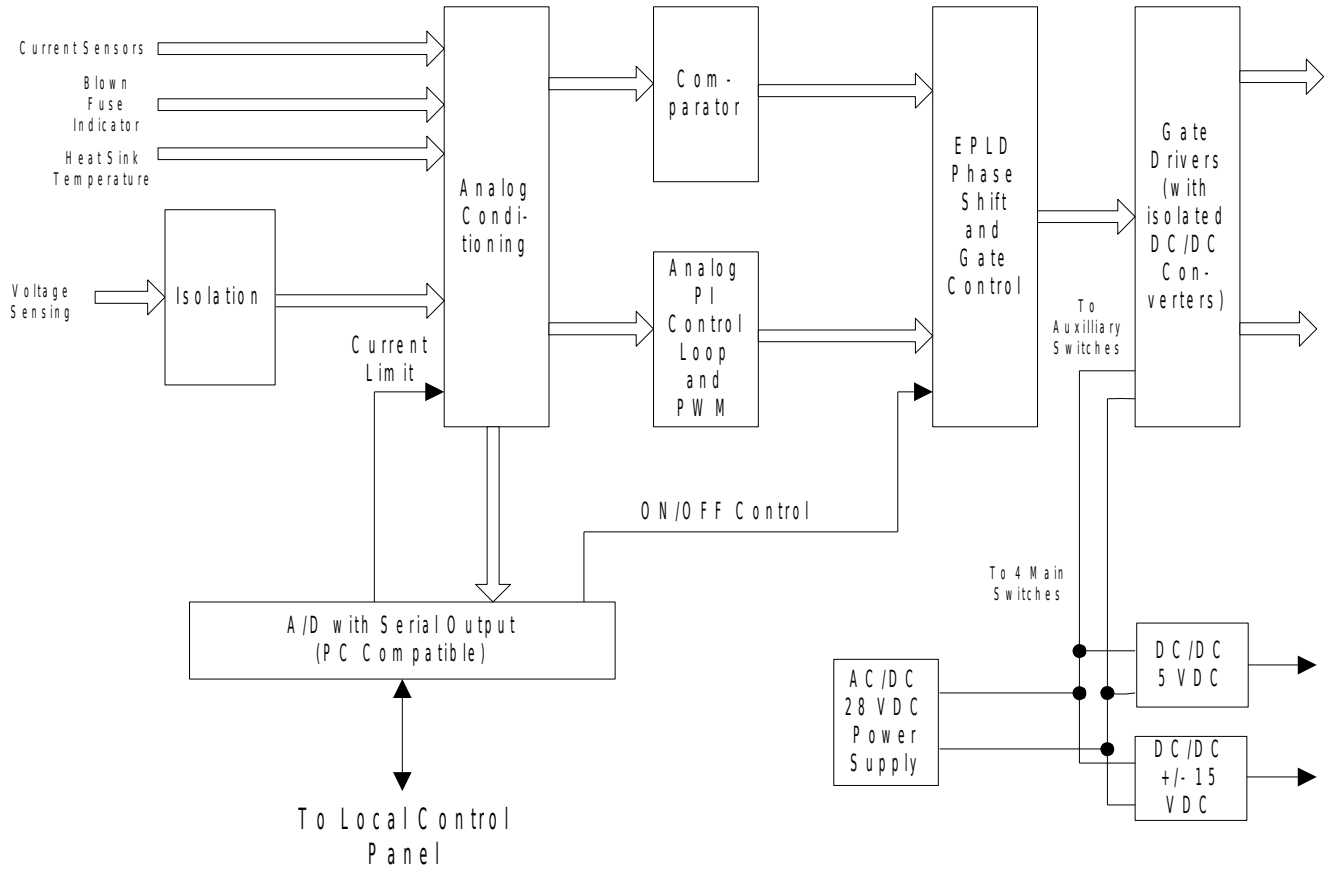
PCM-3A, Version 2

- 100KW, 550-1100 Vdc input, 270 (Variable)Vdc output
- High Power DC-DC converter employing ARCP Topology (Soft Switched)
- Provide Galvanic Isolation and Regulation in one Stage
- High Frequency Transformer (Smaller/Compact)
- Higher Efficiency,Light Weight and Small Size

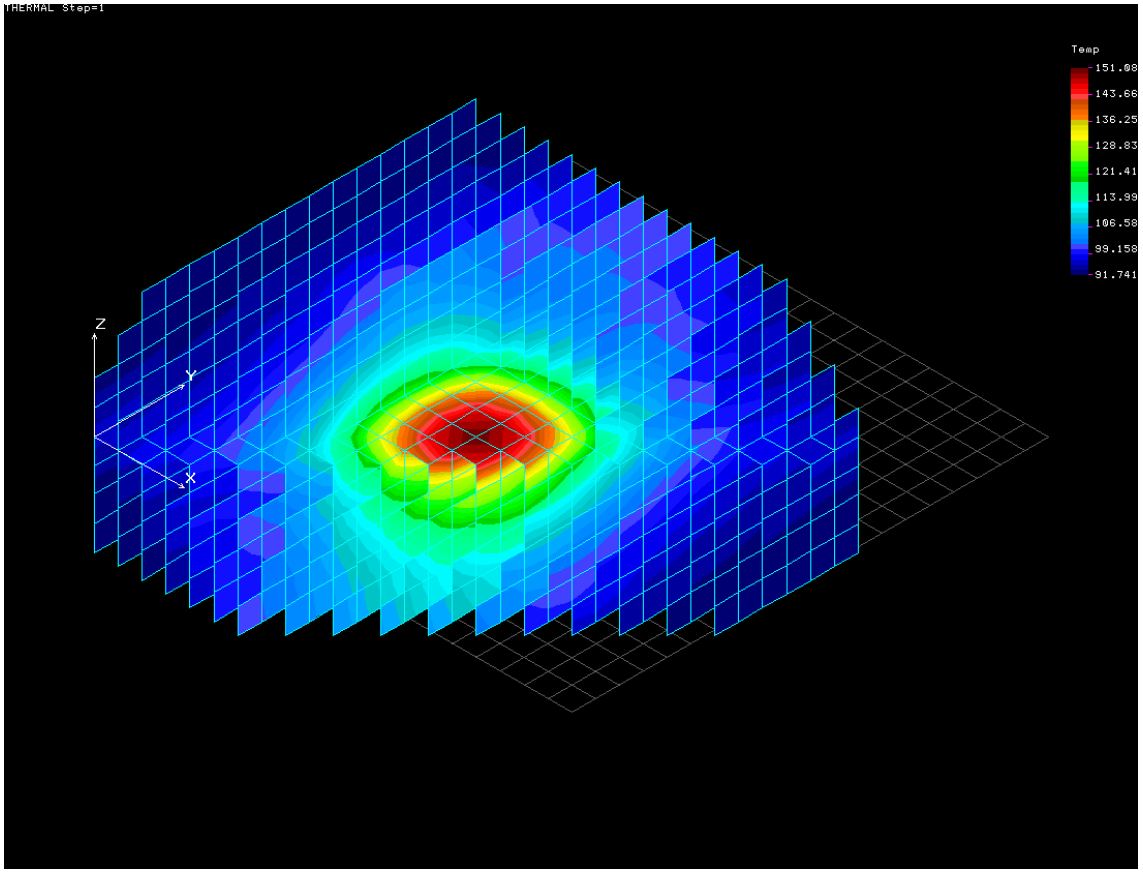
ARCP DC-DC Converter



Control System



Thermal Management



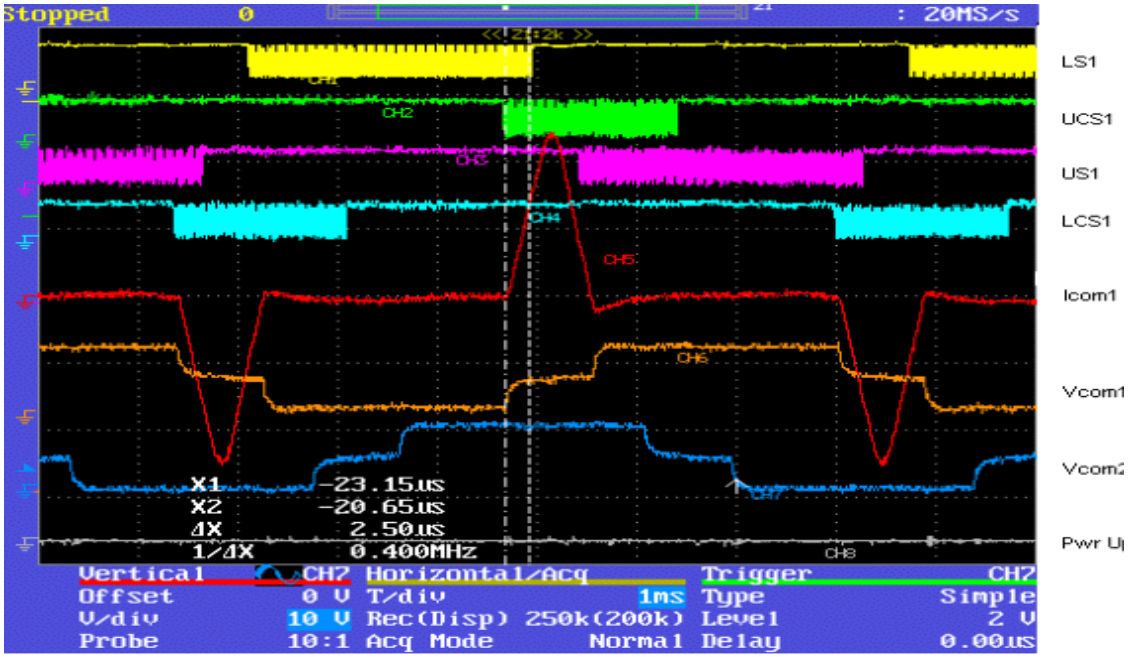
PCM-3 Performance Enhancement

- Thermal Management
  - Heat Pipe Cooling
  - Smaller Fans
  - Lower Acoustic Noise
- Power Plane Upgrade
  - Reduce Electrical Noise
  - Reduce Ringing due to Loop Inductance

Achievement

- Power Rating: 100KW
- Output voltage Regulation: < 0.1%
- Output Ripple: < 0.5%
- Efficiency: 91%
- Input/Output Isolation (Power & Control grounding are Isolated)
- Temperature recorded: < 70C at 100kW @ ambient Temp of 25 C

Sample Data Point



	LEGEND
LS1	Lower Main Switch 1 (Q3)
US1	Upper Main Switch 1 (Q1)
LCS1	Lower Commutating Switch 1 (A2)
UCS1	Upper Commutating Switch 1 (A1)
Icom1	Current through Commutating Switch 1
Vcom1	Voltage across Commutating Switch 1
Vcom2	Voltage across Commutating Switch 2

Efficiency Management

The boost time was calculated based on:

$$I_{peak} = I_{boost} + I_{load} + Vdc/(2*\sqrt{Lr/Cr})$$

or

$$I_{boost} = I_{peak} - I_{load} - Vdc/(2*\sqrt{Lr/Cr})$$

$$t_{boost} = (2*I_{boost}*Lr)/Vdc$$

$$= \{ 2*(I_{peak} - I_{load} - Vdc/(2*\sqrt{Lr/Cr}))*Lr \} /Vdc,$$

where

Lr = Resonance inductor (H)

Cr = Resonant capacitance (F)

t_{boost} = Boost time (sec)

I_{peak} = Peak-current (A)

Vdc = Input bus voltage (V)

I_{load} = Load current (A)

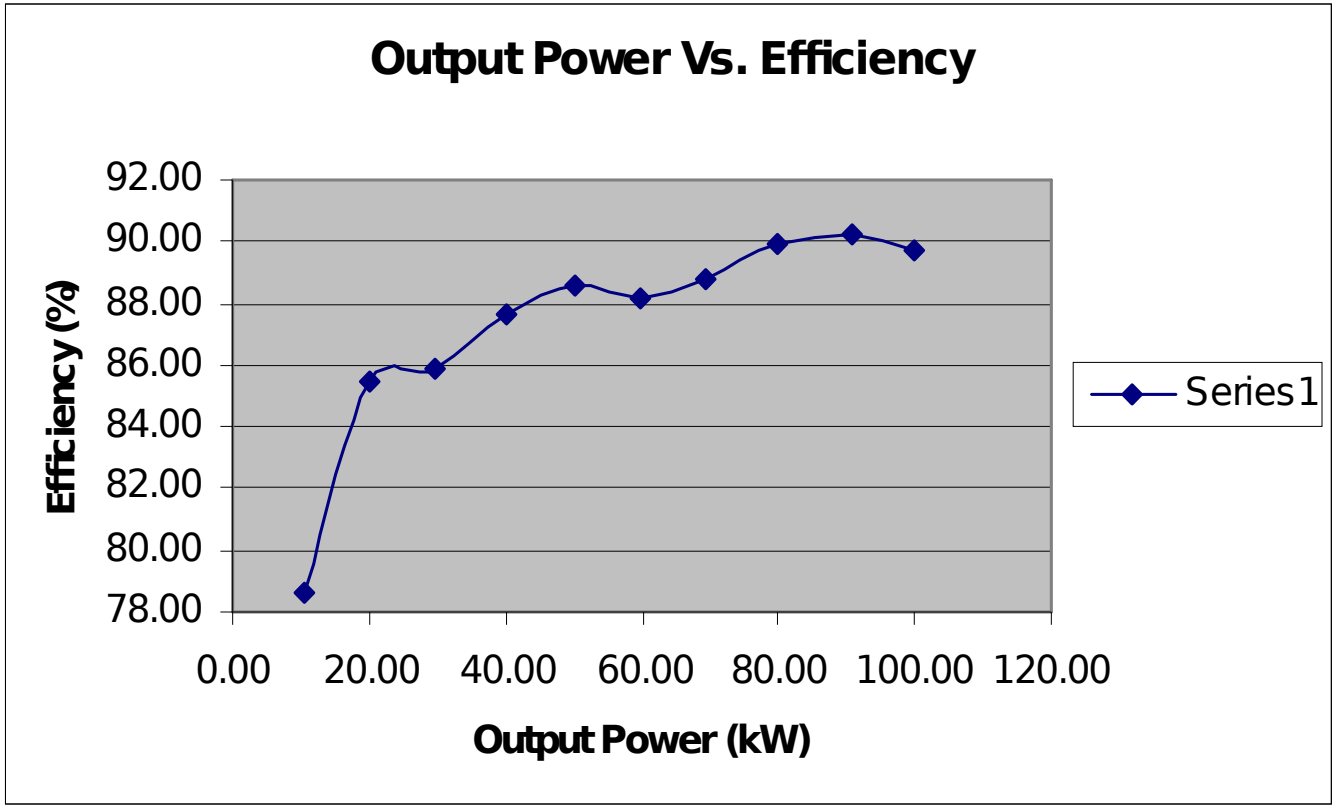
$Vdc = 1100V$, $Lr = 5uH$, $Cr = 0.564uF$, $I_{load} = 136A$ and $I_{peak} = 600A$.

The boost time was $T_{boost} = 2.54\ \mu s$

Test Data

Date	Vin (V)	Shunt (mV)	Iin (A)	Vout (V)	Shunt (mV)	Iout (A)	Vripple (V)	Output Reg. %	Pin (kW)	Pout (kW)	Efficiency %	Vripple %
10/2/02	695.4	4.7	18.8	270.4	3.8	38	0.63	0.00%	13.07	10.28	78.60	0.23%
10/2/02	698	8.5	34	270.4	7.5	75	0.66	0.00%	23.73	20.28	85.45	0.24%
10/2/02	698	12.4	49.6	270.4	11	110	1.06	0.00%	34.62	29.74	85.91	0.39%
10/2/02	696	16.4	65.6	270.4	14.8	148	0.98	0.00%	45.66	40.02	87.65	0.36%
10/2/02	695.7	20.3	81.2	270.4	18.5	185	1.1	0.04%	56.49	50.02	88.55	0.41%
10/2/02	694.4	24.4	97.6	270.3	22.1	221	0.95	0.00%	67.77	59.74	88.14	0.35%
10/2/02	703.7	27.8	111.2	270.3	25.7	257	0.97	0.00%	78.25	69.47	88.77	0.36%
10/2/02	702	31.7	126.8	270.3	29.6	296	1.32	-0.04%	89.01	80.01	89.88	0.49%
10/2/02	695	36.1	144.4	270.4	33.5	335	1.14	-0.07%	100.36	90.58	90.26	0.42%
10/2/02	698.8	39.8	159.2	270.6	36.9	369	0.9	0.00%	111.25	99.85	89.75	0.33%

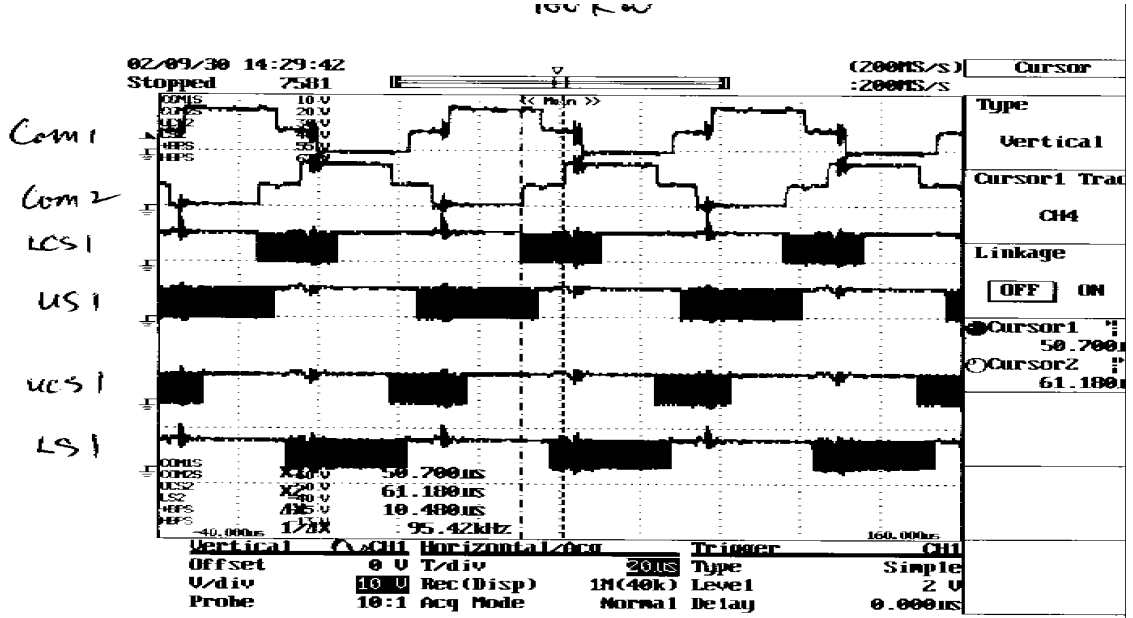
Output Power Vs. Efficiency



Comparison

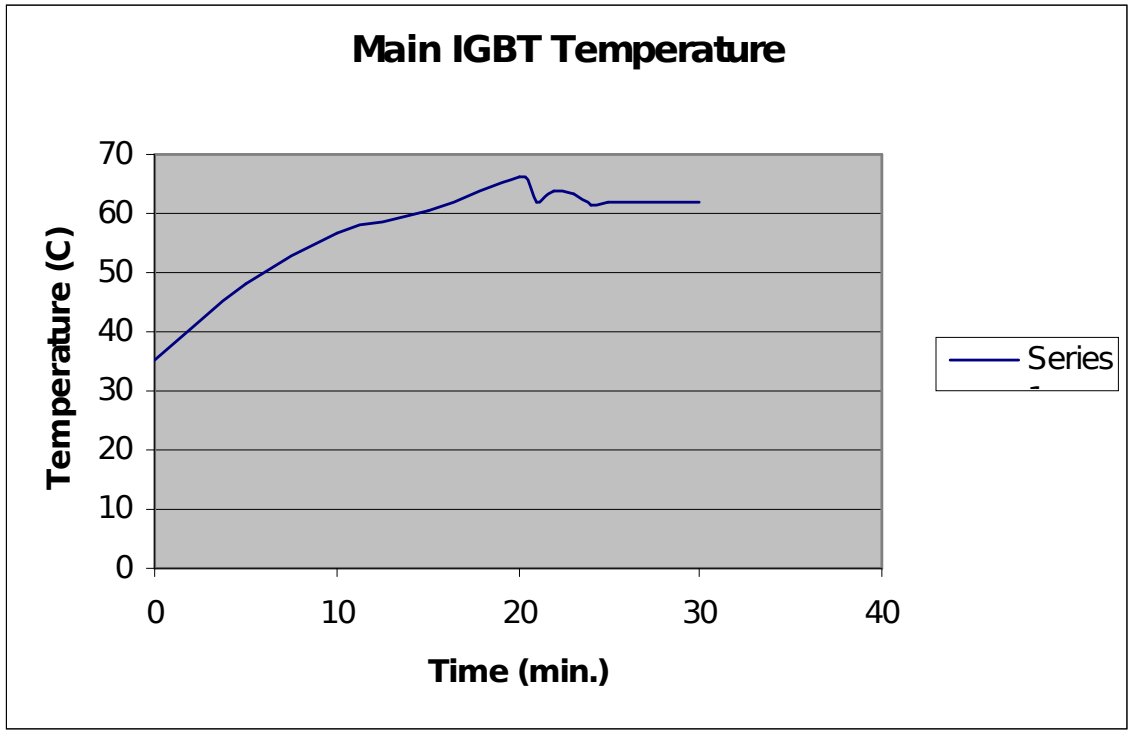
	Hard-switching	ARCP Soft-switching	ARCP Soft-switching with output switch
Power rating	80KW	110KW	150 + KW
Input limit	1100V	800V	1100V
Frequency	4-5Khz	20Khz	20Khz
Number of IGBT's	4	8	9
Heat sink	0.7pu	1pu	1pu
Isolation Transformer	4pu	1pu	1pu
Output inductor	1.5pu	1pu	1pu
Weight	2pu	1pu	1pu
Size	2pu	1pu	1pu

100kW Switching Waveforms



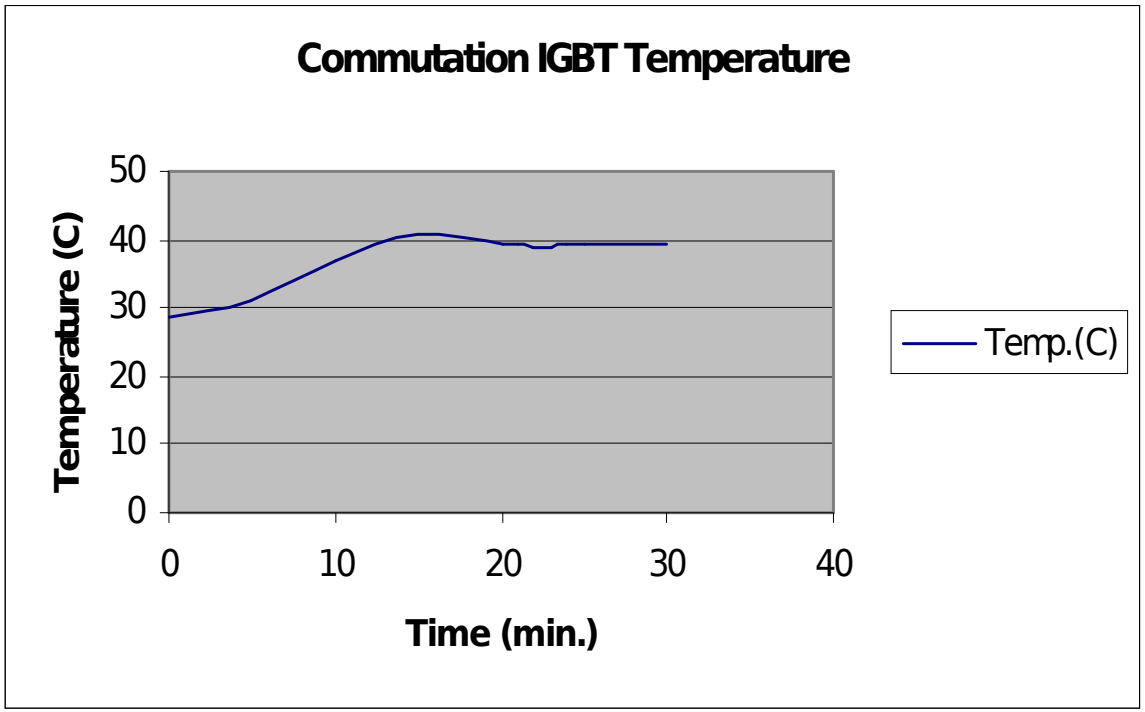
Main IGBT Temperature

Time (min.)	Temp.(C)
0	35.2
5	48.1
10	56.9
15	60.7
20	66.2
21	61.9
22	63.6
23	63.4
24	61.2
25	61.9
30	62



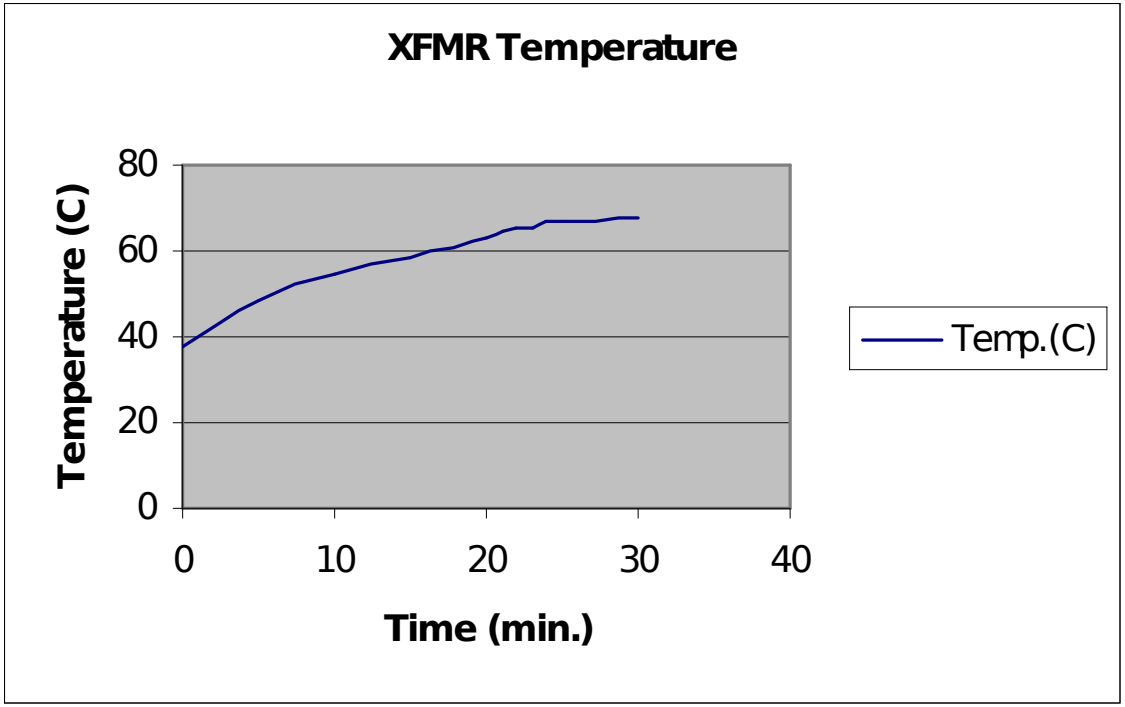
Commutation IGBT Temperature

Time (min.)	Temp.(C)
0	28.4
5	31.1
10	36.8
15	40.6
20	39.2
21	39.1
22	38.7
23	38.7
24	39.5
25	39.5
30	39.4



High Frequency XFMR Temperature

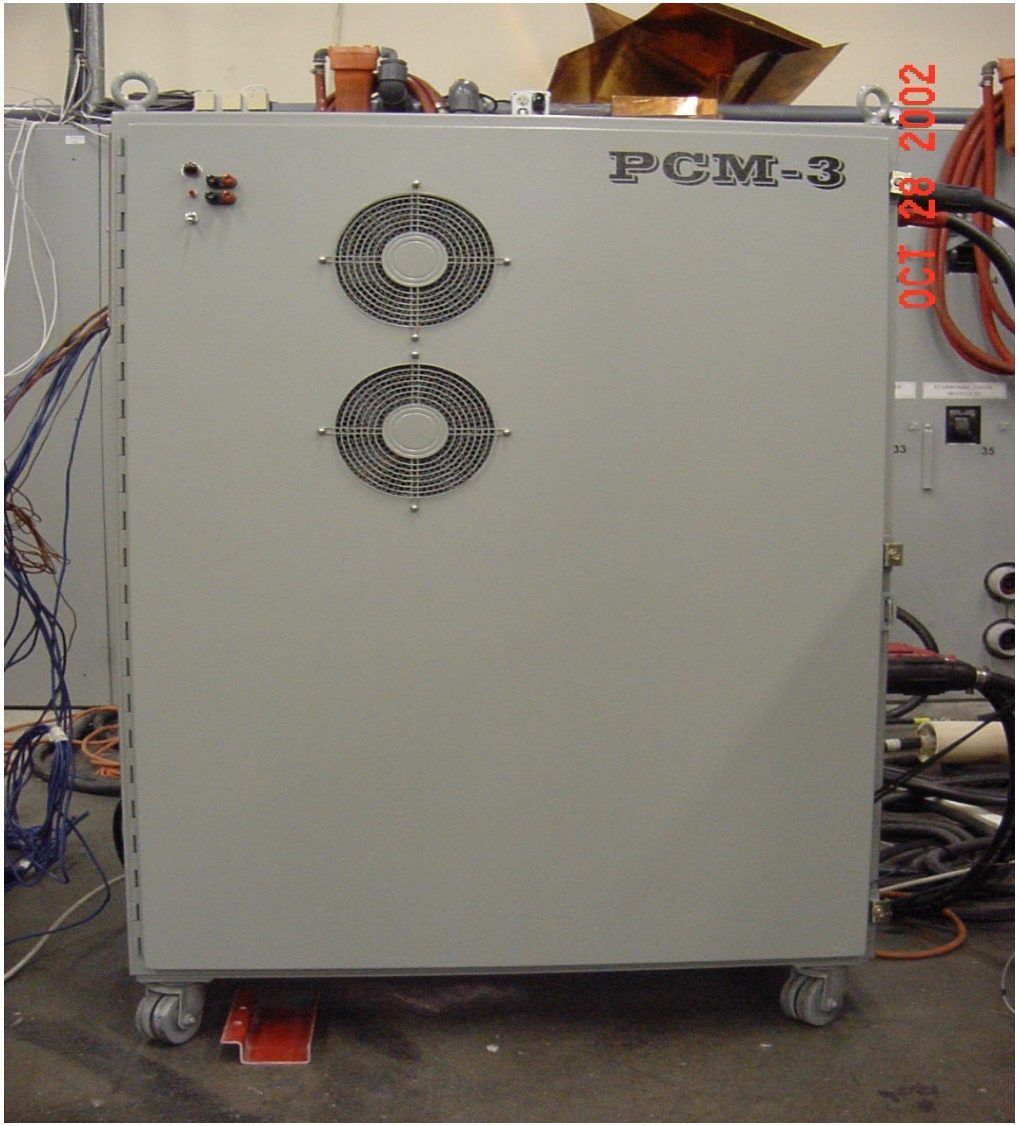
Time (min.)	Temp.(C)
0	37.9
5	48.3
10	54.8
15	58.8
20	62.7
21	64.4
22	65.2
23	65.6
24	66.7
25	67
30	68



Status

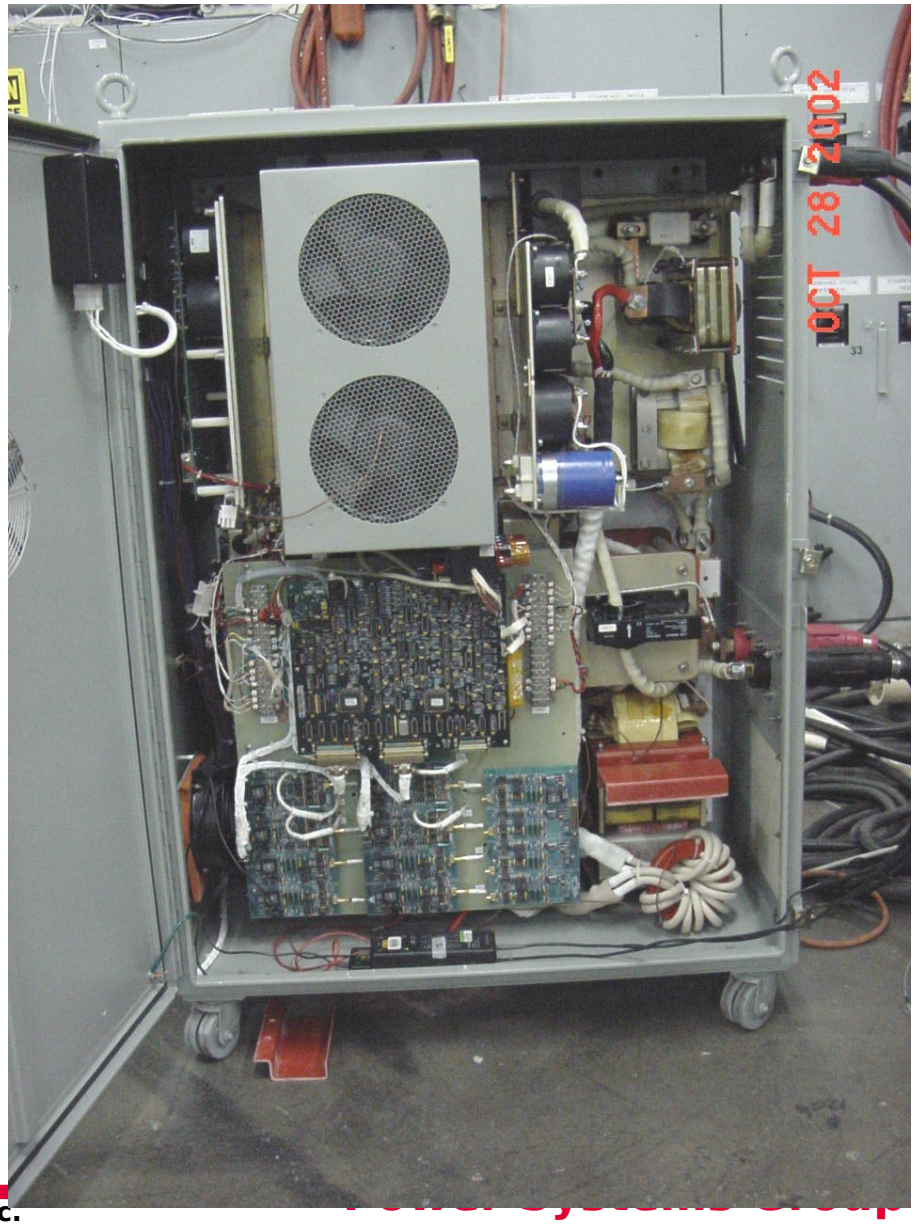
- Packaging
  - Heat Run Test with enclosure
- Ready for Delivery

PCM_3A, Version 2



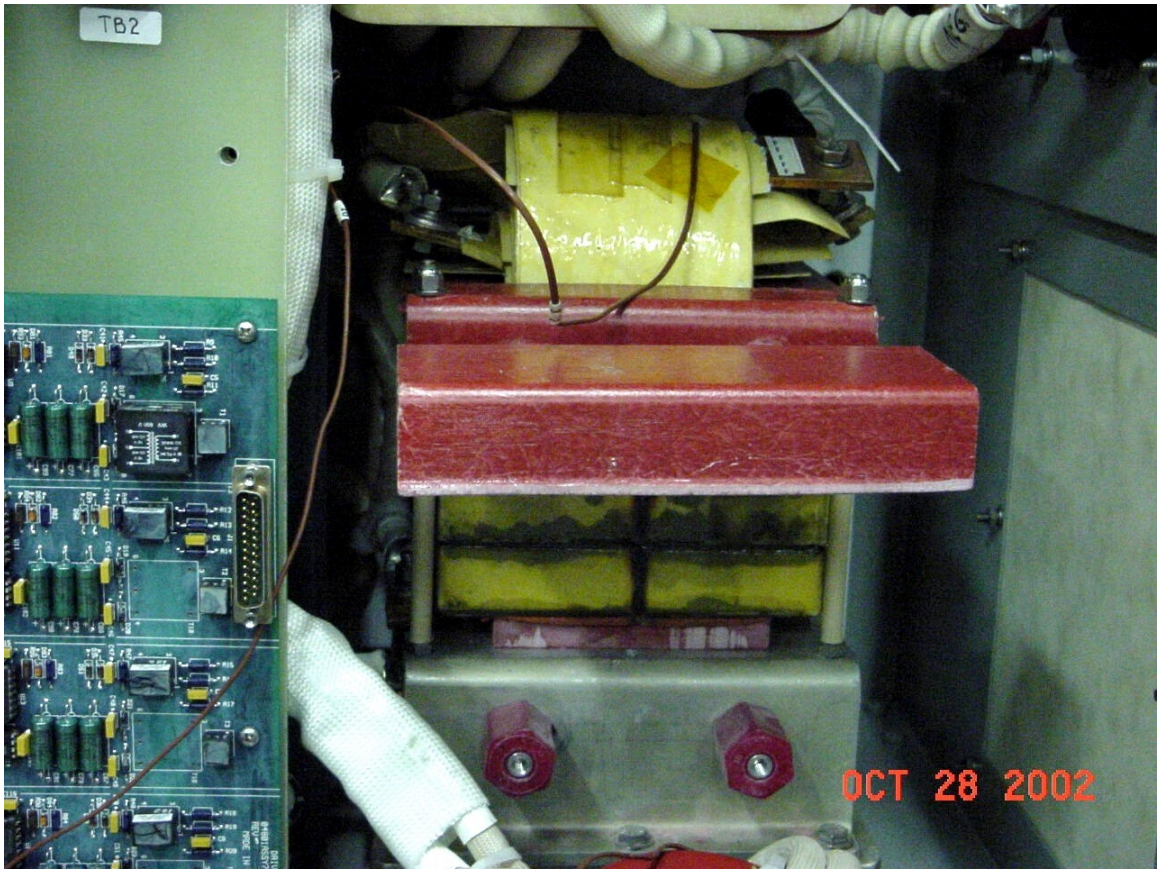
PCM_3A, Version 2 Cont'd

PCM_3A, Version 2 Cont'd



150 KW, 60 Hz Transformer

100 KW High Frequency Transformer



Future Applications

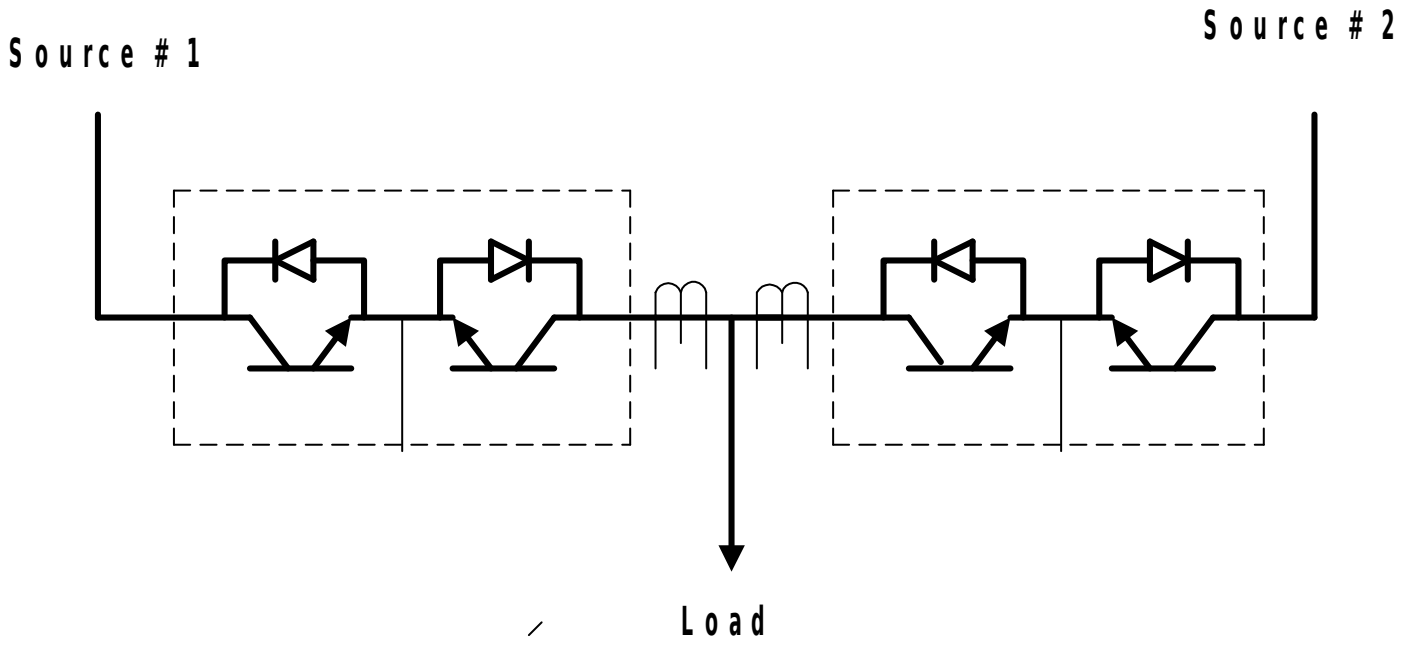
- Military Application:
- Ideal for DC Zonal Distribution Systems
- Isolation/Regulation

- Commercial Application:
- Fuel Cell application. (Wide range Input 550-1100)

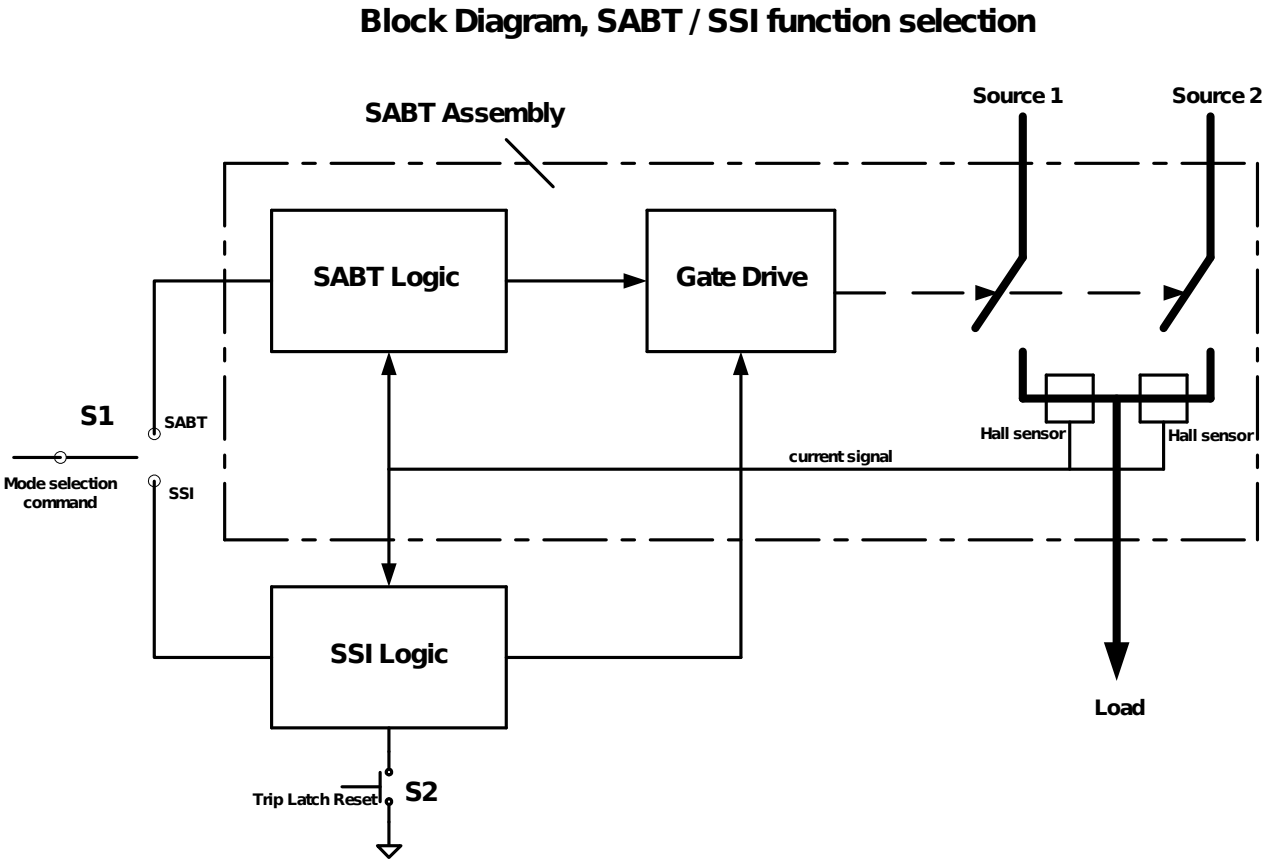
Solid State Quiet Switch

- Quiet, Fast (er) and More Controllable Switching Technology
- Dual Use Switch
  - Static Automatic Bus Transfer (SABT) Function
  - Solid State Interrupter (SSI) Function
- Employs Two Power Switching Components
  - PEBB-MCT
  - IGBT
- Employs Mature SABT Technology

SSQS With PEBB Modules



SSQS Control Diagram



PEBB-MCT Performance

- MCT Module
  - N-Type device for AC application
  - Model # SPPM800AC13A0
  - Gate Drive Board # SPDR12
- MCT is proved to be a high speed switch (Work as SABT, the transfer time is less than 50us)
- Performance Shortcomings
  - MCT on the pick-up side experiences transient bouncing every time switching
  - MCT current interrupting capability.

Current Interruption Test with IGBT

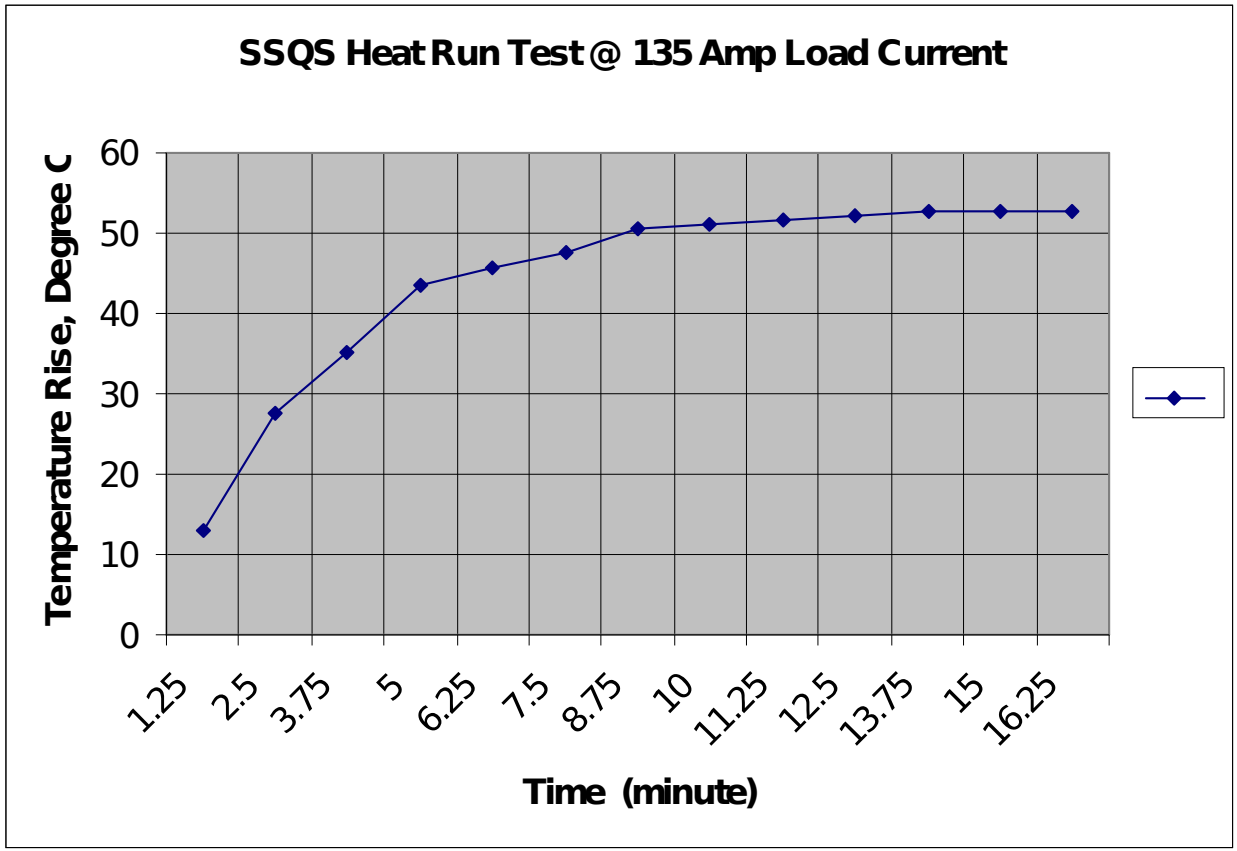
SSQS successfully interrupted current at multiple levels: from 50 Amp to 500A, at different power factor. During the test, voltage across IGBT was monitored. Test records showed that the switching transient voltage was clamped by the MOV and did not exceed the IGBT voltage rating.

Current Interruption (Amp, rms)	Power factor	OK/ Fail	Max.Transient voltage across IGBT [1]	Remark
100	1.0	OK	900V	[1]
]100	0.8	OK	1100V	
200	1.0	OK	1200V	
200	0.8	OK	1200V	
400	1.0	OK	1250V	
400	0.8	OK	1250V	
500	1.0	OK	1250V	
500	0.8	OK	1450V	
500	0.2	OK	1450V	[2]

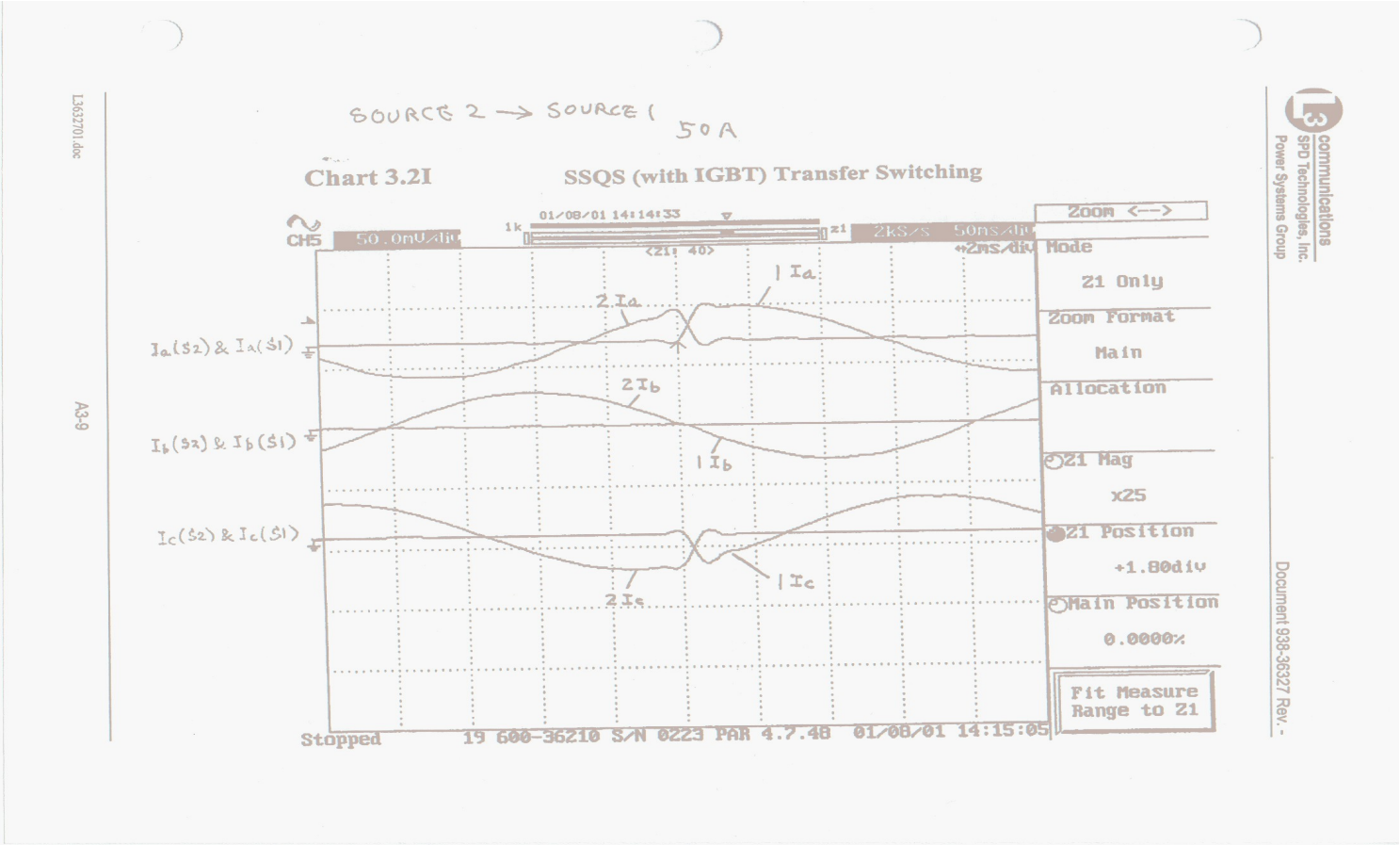
[1] Transient voltage clamped by 1480V rating MOV. The IGBT voltage rating is 1700V.

[2] Low Power Factor is for Short Circuit Current Interruption Test

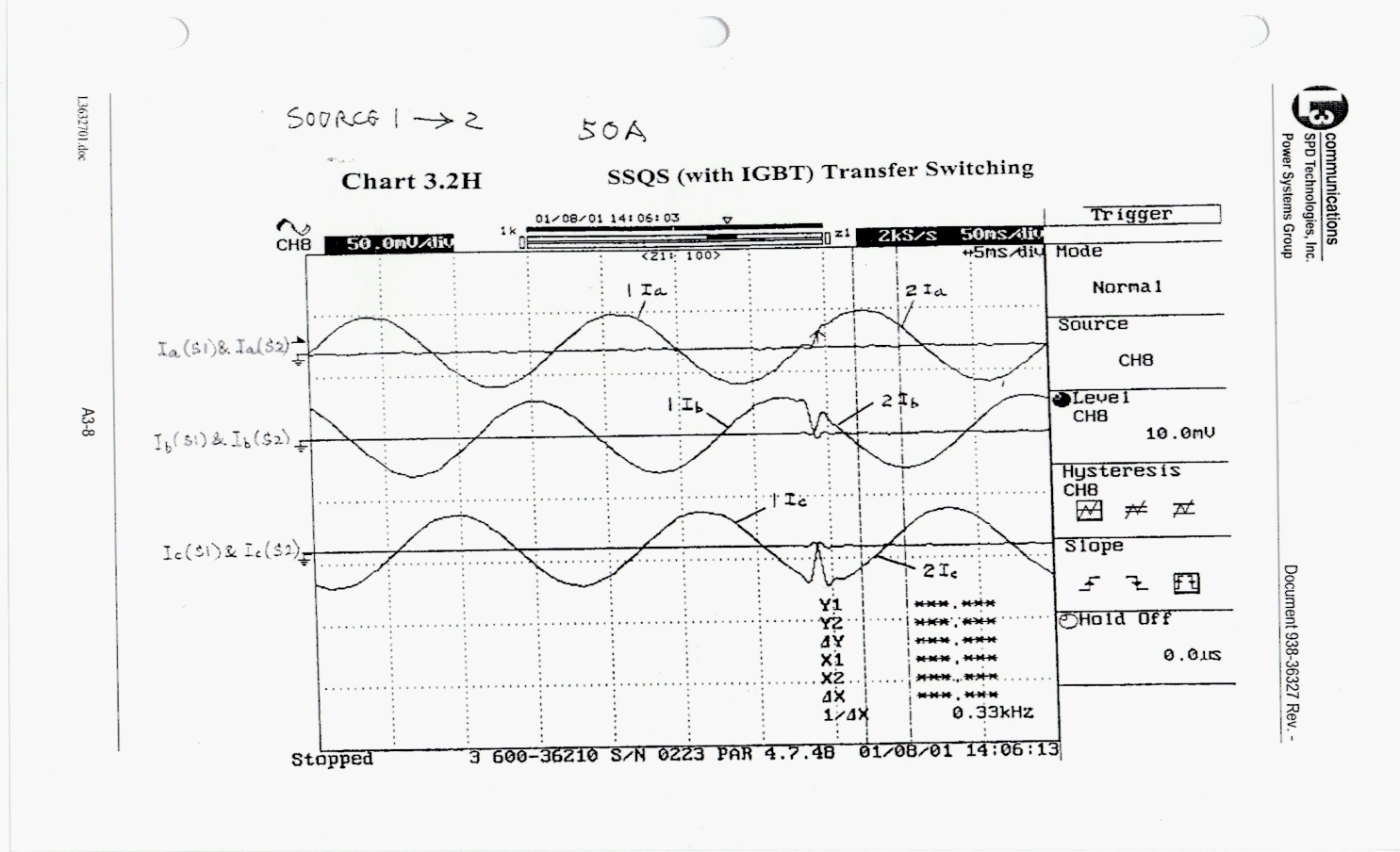
Heat Run Test with IGBT



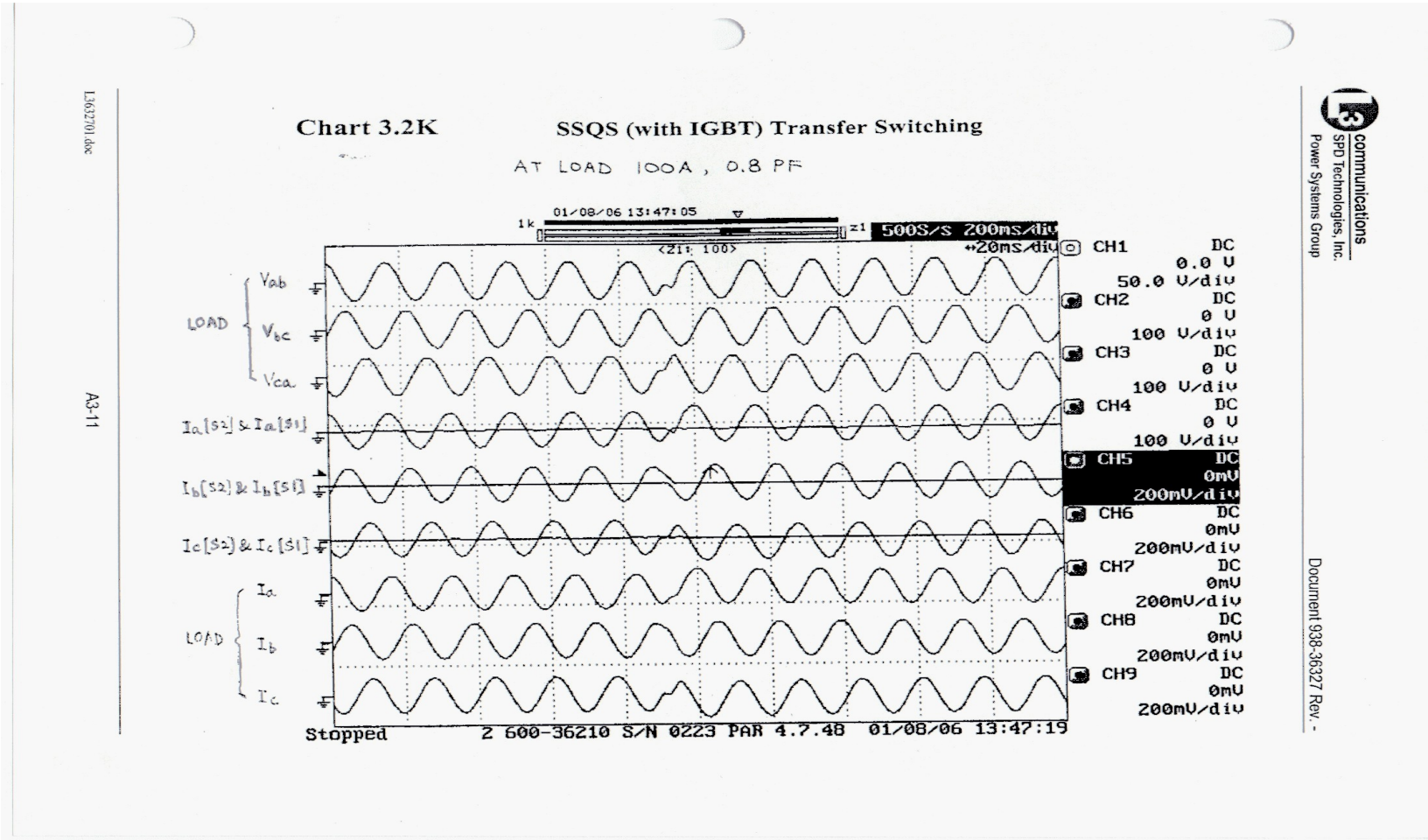
Transfer Switching with IGBT



Transfer Switching with IGBT



Transfer Switching with IGBT

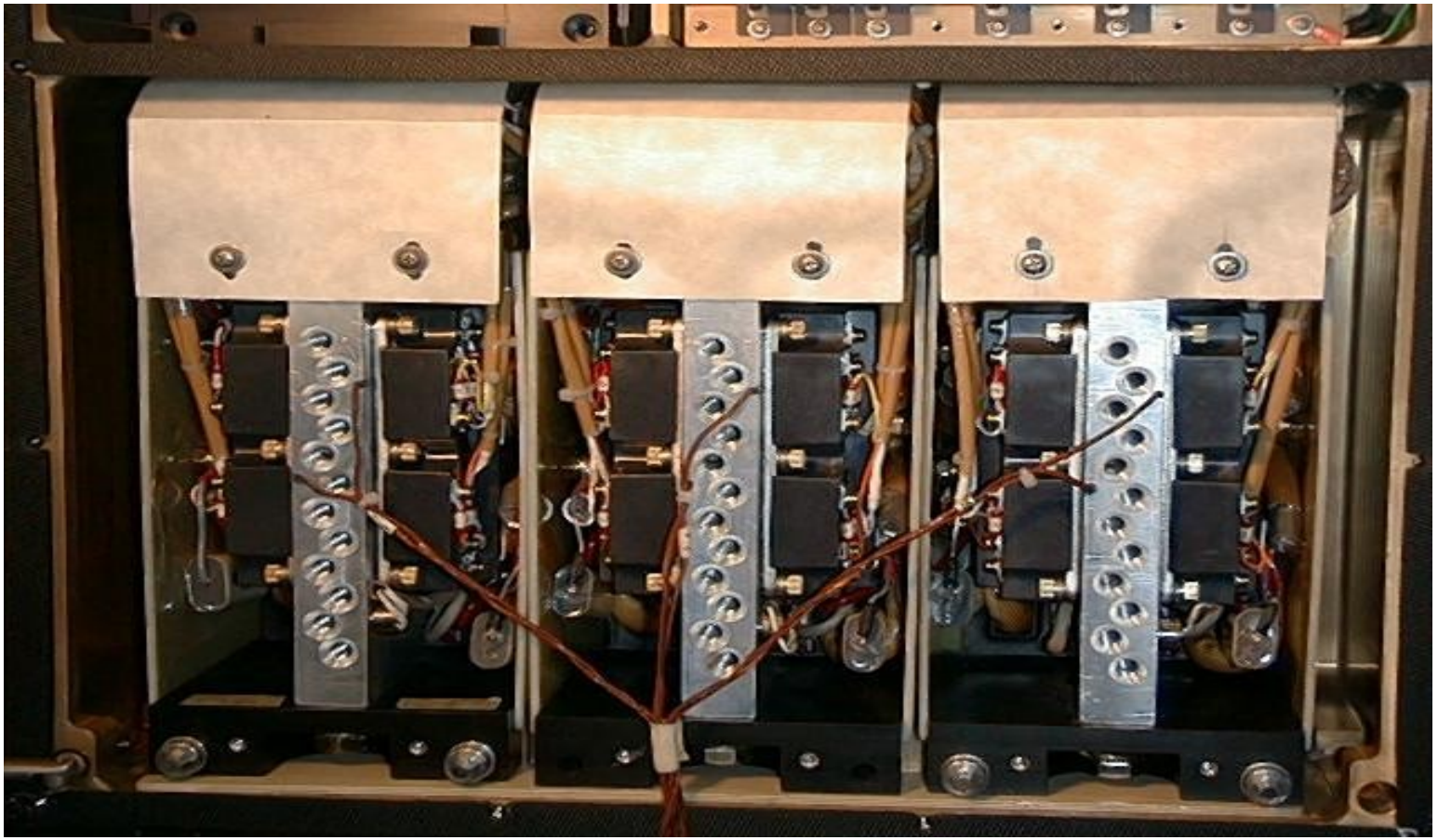


Test Summary

Application	Major required parameter in application	MCT	IGBT	SCR [3]
SABT	ABT transfer time	<50 us [8]	40 us	4 ms
SABT / SSI	Forward voltage drop (V)	1.85 V [5]	1.6 V [5]	0.8 V
SABT / SSI	Power loss at 50 Amp load (W) per switch	92 W	80 W	40 W
SABT / SSI	Power loss at 50 Amp for 3-phase (W)	278 W	240 W	120 W
SABT / SSI	Efficiency at 50 Amp @ 0.8 PF	99.2%	99.4%	99.6%
SABT / SSI	Current carrying capability (A)	130 [2]	135 [2]	400
SSI	Current interruption capability (A)	<300A [1]	>500A [1]	40 KA [4]
SABT / SSI	Current withstanding capability (KA-ms)	Not tested [1]	Not tested [1]	30KA, 28ms
SSI	"Current limit control" technique compatible ?	Yes	Yes	No
SSI	Maximum voltage across the switch during current interruption	1480 V [6]	1480 V [6]	735 V [7]

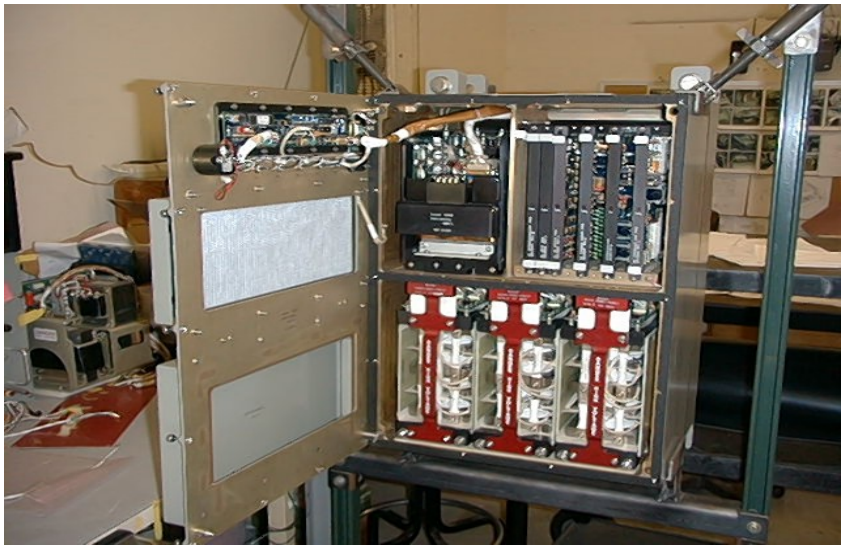
[1] When apply current limit function in the control algorithm (to be developed), IGBT (or MCT) will not be subject to the requirement of withstanding or interrupting high current.
[2] Limited by the breadboard heat sink that is designed for 50A continuous current application.
[3] Performance data based on the existing 400A SABT.
[4] SCR interruption rating based on SSI 900A test result at 60Hz, 450V.
[5] Forward voltage drop was measured including series diode volt-drop at 50 Amp load.
[6] Transient voltage is clamped by the MOV across the switch
[7] Maximum steady state voltage across SCR = 2x(1.414x450/1.732) = 735V
[8] When use MCT as switch, multiple bouncing was found during transfer operation. Refer to section 4.3 for detail.

Three Phase IGBT Stacks



MCT Stacks Cont’d

Complete SSQS with SCR Stacks



Transition of SSQS to Military

- Suitable for Surface & submarine applications
- Potential motor Soft start application
- Ideal for electrical re-configurable operation
- Being considered for ship zonal power distribution system
- Design is being incorporated into UPS technology for both commercial and military applications

Future Capability

- 400 Hz Application (SCR or IGBT)
- DC Hz Application (IGBT)
- Current Limiting function to compensate for device weakness in comparison to SCR (IGBT or MCT)